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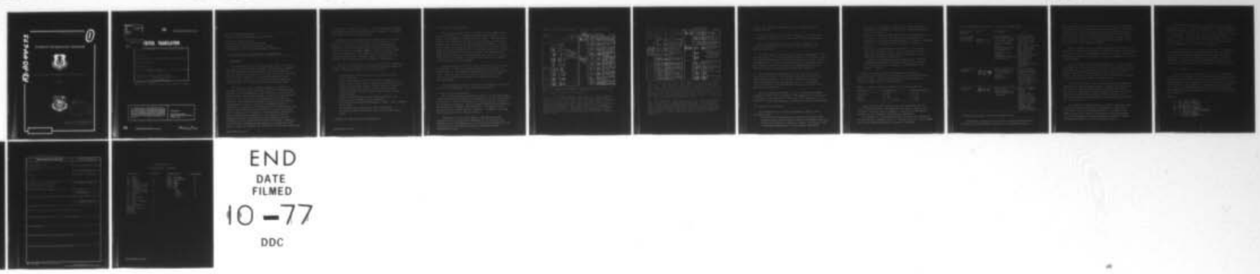

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FRICTION WELDED CONFIGURATIONS FOR CONSTRUCTION

by

S. Buchholz

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FTD ID(RS)I-1724-76

EDITED TRANSLATION

FTD-ID(RS)I-1724-76 29 December 1976

CST76042712

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English pages: 13

Source: Schweisstechnik, Vol 24, Nr 11, November 1974, PP. 509-512.

Country of origin: East Germany
Translated by: LINGUISTIC SYSTEMS, INC.
F33657-76-D-0389
C. E. Claff, Jr.
Requester: ASD/ETIL

PREPARED BY:

TRANSLATION DIVISION
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FRICTION WELDED CONFIGURATIONS FOR CONSTRUCTION

0. Introduction

The increasing use of friction-welded joints in vehicular, machinery, and earth-moving equipment construction, in machine tool and automotive manufacturing and for other industrial purposes requires consideration of certain structural principles of the welding component. The conditions under which the joining process proceeds to yield a rotationally symmetrical joint are basic for a position suitable for manufacturing.

The joining process is characterized by a temporarily applied frictional action resulting from relative motion under pressure, with heat generation and conduction, extrusion of the plastic metal from the work surface, cessation of the relative motion in 0.1 to 0.5 sec., and application of the welding pressure. The welding particulars are based on time-pressure programs and are chosen in view of the working material or combination of materials, the dimensions of the joining area and shape of the workpiece, the preparation of the work surfaces, and the capacity of the machine. The shortening, formation of beads, and mechanical properties of the welded joint are dependent upon the optimization of the parameters and the suitability of the conditions for friction welding. Automation of the friction welding process produces a consistently high-quality joint, but requires the observation of definite precautions

of condition in order to be able to position the parts, tighten them expediently, weld them with optimal parameters, and remove them after cessation of the pressure.

Builders and technicians have the possibility of solving questions of materials substitution, the economical use of materials, conservation of the pressure and manufacturing capacities, use of high-productivity manufacturing processes (such as precision forgings, rollers, hydraulic presses, dies, patterns, heated rolls, and drawing) for the manufacture of semi-finished goods of the proper shape by proper use of the process, and to promote genuine economies in manufacture.

The areas of application of friction welding are determined by the shape of the work piece, the material, and the number of pieces. Predestined areas of use up to now are:

- In machine tool fabrication: drills, reamers, milling cutters and hobs;
- In the tractor and automobile industries: bimetallic valves, drive shafts, axles, conical gear drives, steering journals, motor brake shafts, clutch shafts, universal joints, keyed drives, steering shafts, piston rings, suspension tubes, pressure rolls, levers, flange joints, turbine shafts;
- In power drive manufacture and machine-building: spur gears and bevel wheels, axles, and shafts.
- In earth-moving machinery manufacture: shafts, chain elements, axles, hubs.
- In bicycle manufacture: axles, hubs, foot-cranks
- In chemical plant construction: pipe joints, pipe flange joints.

1. Appropriate Manufacturing Configurations

1.1 Principal Considerations

The friction welding process requires the development of at least one part with a circular or annular shaped surface. In Table 1 are assembled the dimensions and shapes. The applicable region up to a diameter of 5 mm has scarcely been used up to the present time, because of the high machine requirements. In the region from 5 to 150 mm, currently chiefly cross sections of 8 to 50 mm are friction welded. This is the range in which the largest number of parts occur in the users' plants. The machines are graduated for diameter ranges from about 6 to 15 mm, 12 to 30 mm, 20 to 40 mm, 30 to 50 mm. In machines with two or more speeds, the diameter ranges are broadened.

Friction welding of pipes is associated with special tension arrangements, in order to prevent deformation of the pipe by tension forces. The conditions become difficult with thin-walled pipes. The pipe ends must be tightened short, and the outer shape of the tightening jaws must be suitable for the pipe outside diameter.

Friction welding machines can be used in welding of pipes for larger outside diameters, as in solid cross sections.

1.2 Local joint configurations

The principal shapes displayed in Table 1 for friction welded joints are modified according to the dimensions of the joined parts, the materials, and the requirements for bead formation, strength, and economical formation. With increased automation and heightened requirements for strength and reliability, the expense of preparation of the contact surfaces increases. In Table 2 are shown the preparations of the joining points.

Proceeding from the basic shapes, users report various preparations of joining points depending on the materials and dimensions, with consideration of the economical preparation of the joining points, the friction process, bead formation and

Table 1. Dimensions of the joint locations in friction welding.

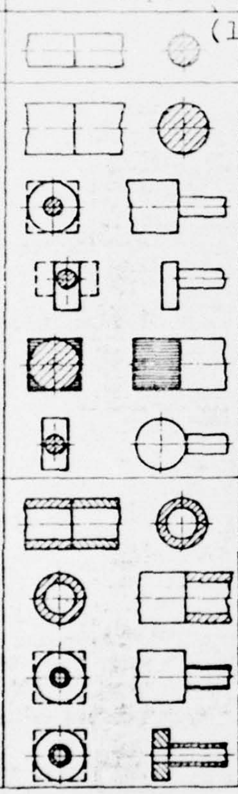
Dimension	Shape	Notes
≥ 1		(1) Drehzahlen bis 100000 min^{-1} niedrige Drücke
5 ... 150		(2) Drehzahlen 300 ... 5000 min^{-1} Erwärmungsdruck p_e = 1 ... 20 kp/mm^2 Verschweißdruck p_{schw} = 2 ... 35 kp/mm^2
10 ... 400		

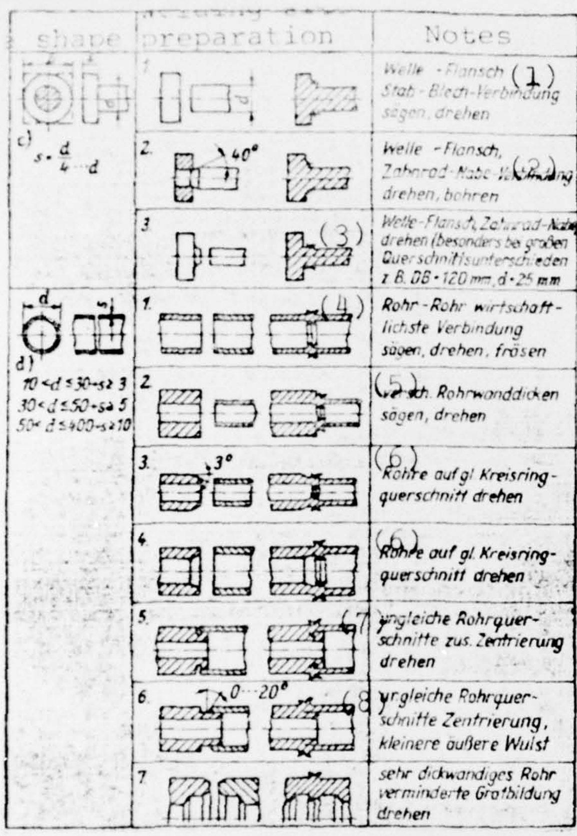
Table 2. Preparation of the welding sites for friction welding

Base shape	Welding site prep./bead shape	
a) 	1 (0 ... 1°) 	häufigste Form sägen, drehen, fräsen, hobeln (abhacken m. 2 m/s) (1)
	2. (1 ... 5°)	große Durchmesser drehen, fräsen (2)
	3.	große Durchmesser Verkleinern d. äußeren Wulst, drehen, fräsen (3)
	4.	große Durchmesser Verkleinern d. Fügequerschnitts drehen, bohren (4)
b) a, D, d; a > d	1. (0 ... 1°)	normale Beanspruchung wirtschaftlichste Vorbereitung $\frac{D}{d} \leq 3$ drehen, sägen, fräsen (5)
	2. (3 ... 5°)	große Durchmesser kleinere Wulstausbildung drehen, fräsen $\frac{D}{d} \geq 3$ (6)
	3. (3 ... 5)	große Durchmesser kleinere Wulstausbildung drehen, fräsen (7)
	4.	Kleinere Wulstausbildung, kleinerer Fügequerschnitt drehen, fräsen (8)
	5	Verbesserung der Wärmeführung drehen (9)
	6. (30°)	(10) gleiche Verbindungsquerschnitte kleiner Steifigkeitssprung drehen

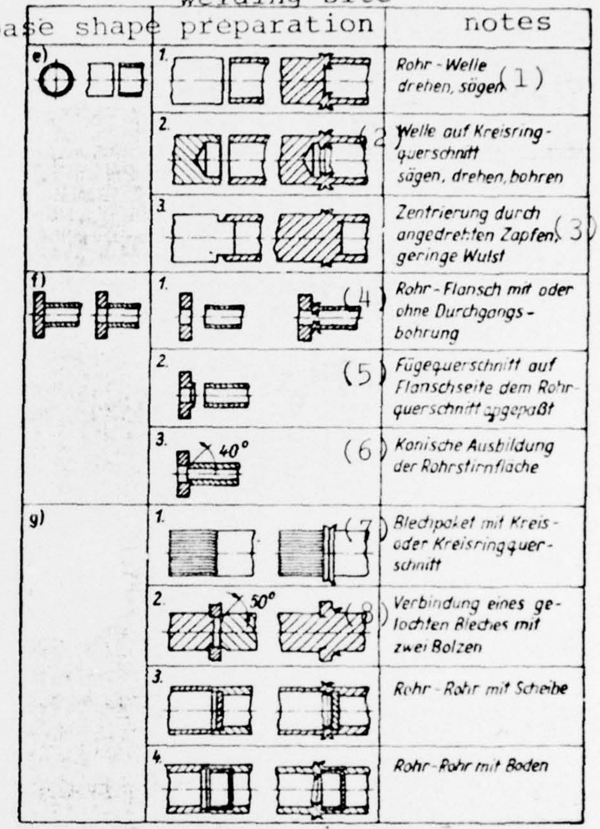
Key: (1) Rotational speed up to 100,000 rpm, low pressures; (2) Rotational speed 300-5000 rpm. Heating pressure Ph = 1 - 20 kp/mm^2. Welding pressure p_W = 2-35 kp/mm^2

Key: (1) Most frequent shape: saw, turn, mill, plane (cut-off at 2 m/s); (2) Large diameter: turn, mill; (3) Large diameter. Reduction of outer bead; turn, mill; (4) Large diameter, Reduction of joint section: turn, drill; (5) Normal requirement. Most economical preparation D/d≤3: turn, saw, mill; (6) Large diameter. Smaller bead formation: turn, mill D/d>3; (7) Large diameter Smaller bead formation: turn, mill; (8) Smaller bead formation, smaller joining section: turn, mill; (9) Improvement of heat conduction: turn; (10) Equal joining sections smaller fissurable fault: turn.

Table 2 Continued.



shape	welding site preparation	Notes
c) $s = \frac{d}{4} \cdots d$	1.	Welle - Flansch (1) Stab - Blech - Verbindung sägen, drehen
	2. 40°	Welle - Flansch, Zahnrad - Nabe - Verbindung (2) drehen, bohren
	3. (3)	Welle-Flansch, Zahnrad-Nabe drehen (besonders bei großen Querschnittsunterschieden z.B. DB = 120 mm, d = 25 mm
d) $10 < d \le 30 \rightarrow s \ge 3$; $30 < d \le 50 \rightarrow s \ge 5$; $50 < d \le 400 \rightarrow s \ge 10$	1. (4)	Rohr - Rohr wirtschaftlichste Verbindung sägen, drehen, fräsen
	2.	(5) versch. Rohrwanddicken sägen, drehen
	3. 3°	(6) Rohre auf gl. Kreisring-querschnitt drehen
	4.	(6) Rohre auf gl. Kreisring-querschnitt drehen
	5. (7)	ungleiche Rohrquerschnitte zus. Zentrierung drehen
	6. 0···20° (8)	ungleiche Rohrquerschnitte Zentrierung, kleinere äußere Wulst
	7.	sehr dickwandiges Rohr verminderte Gratbildung drehen



base shape	welding site preparation	notes
e)	1.	Rohr - Welle drehen, sägen (1)
	2. (2)	Welle auf Kreisring-querschnitt sägen, drehen, bohren
	3.	Zentrierung durch angedrehten Zapfen, geringe Wulst (3)
f)	1. (4)	Rohr - Flansch mit oder ohne Durchgangs-bohrung
	2. (5)	Fügequerschnitt auf Flanschseite dem Rohrquerschnitt angepaßt
	3. 40° (6)	Konische Ausbildung der Rohrstirnfläche
g)	1. (7)	Blechpaket mit Kreis- oder Kreisringquerschnitt
	2. 50° (8)	Verbindung eines gelochten Bleches mit zwei Bolzen
	3.	Rohr - Rohr mit Scheibe
	4.	Rohr - Rohr mit Boden

Key: (1) Shaft-Flange, Bar - Plate joint: saw, turn; (2) Shaft-Flange, Spur gear-hub joint: turn, drill; (3) Shaft-Flange, Spur gear - hub: turn (especially for large crosssectional differences, for example DB=120 mm, d=25 mm); (4) Pipe - pipe most economical joint: saw, turn, mill; (5) Different pipe wall thicknesses: saw, turn; (6) Pipes with the same annular crosssection: turn; (7) Dissimilar pipe crosssections at the center: turn; (8) Dissimilar pipe crosssection at the center, smaller outer bead; (9) Very thick-walled pipe, reduced ridge formation: turn.

Key: (1) Pipe-shaft: turn, saw; (2) Shaft to annular crosssection: saw, turn, drill; (3) Centering by turned peg: small bead; (4) Pipe - flange with or without concentric bore; (5) Joining cross-section on the flange side adjusted to the pipe crosssection; (6) Conical formation of the pipe front surface; (7) Packet of plates with circular or annular crosssection; (8) Joining a bored plate with two pegs; (9) Pipe - pipe with washer; (10) Pipe - pipe with bases.

removal, the strength requirements and the economics of the joining process.

The basic shape a is used under examples 2, 3, and 4, with the purpose of minimizing the joined surface and bead formation.

The variations from b. 2 to b. 6 serve to improve heat conduction during the friction process and to heighten the strength properties.

The basic shape c is varied by the various preparations, for the same reasons. In this way, shaft, flange, or rolled bar joints are friction welded with special formations of the flange, sheet, or shaped part. The multiple possibilities for preparation of the basic shapes c and d also promote the strength properties and improve the friction welding process and bead formation.

New technological possibilities arise from the joining of several parts in one friction process, without the necessity of using special machines. The friction welding of packets of sheet metal with bar or pipe material (g. 1) is a favorable joining possibility with appropriate tension on the sheet, even with different materials.

The joint shapes used under g. 2 to g. 4 show considerable economies through friction welding. The preparation of the joining points must be carried out in each case so that the parts to be joined are seized simultaneously or stepwise in the friction process.

1.3 Examples of the Process

The economical use of friction welding is found in the following areas:

- Similar or differing materials that heretofore have been manufactured by other welding methods, for example resistance welding or electric arc welding, brazing, or riveting, with considerable expenditure of time, energy, additional

materials or technology. Production is simplified, the processing is automated, and previously prepared individual parts can be used.

- Work pieces that previously were completely manufactured in one piece by turning. The parts can be resolved into components, and can be pre-manufactured on automatic equipment; they can be so configured that a minimum of turning is required.
- Work pieces that heretofore were forged at high expense with large material losses. There are possibilities of combinations between forged, cross-rolled parts, rolled materials, and semi-finished parts.

Engineers and technicians must know clearly, that the attainable dimensional precision depends on the condition of the machine and the tolerances of the prepared work pieces. (Table 3).

With increasing precision requirements, the efforts in preparing the work pieces and the demands on the friction welding machine increase. Specific appropriate machines customarily guarantee normal precision in dimensions.

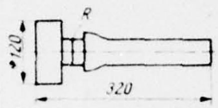
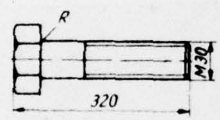
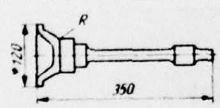
Table 3: Specific values for Precision in Friction Welding

Precision	Eccentricity	Length Tolerance
Very high	0.05 mm	$\pm$ 0.1 mm
Normal	0.2 mm	$\pm$ 0.5 mm
Coarse	0.5 ... 1.0 mm	$\pm$ 1.0 mm

While the principal possibilities and indications for the use of friction welding configurations are shown in Tables 1 and 2, Table 4 contains several examples of application with special emphasis on the economical and technical advantages.

The examples of application discussed can only be indications of the principal problem solutions. Already there are a large number of friction welded construction elements in industry.

Table 4: Examples of preparation of friction welded parts

Designation Materials	Sketch	Manufacture old	new
Turbine shaft X10CrNiWVTa 18.9/25CrMor		Flame butt welding -High material loss by turning to form a cap on washer side (cap length 40 mm) -High material loss by consumption (20 mm) -High energy consumption -Unfavorable pressure possibilities	Friction welding -low material loss by turning (cap length on washer side 3 mm) -Low turning expense -Low compression loss (shortening from friction welding 2 mm) -Favorable pressure and centering possibilities -Low energy consumption -Industrial health advantages
Hexagonal bolt 37 MnSi5		Complete machining -1.6 kg material loss per bolt by turning -High turning expense	Friction welding -Lowered material loss from turning -Conservation of turning capacity -Use of semi-finished materials (round or hexagonal stock)
Drive shaft 16 MnCr5		Manufacture by free-form forging -High material loss for finishing by machining	Friction welding -Material substitution Flange: C15 Shaft: 16 MnCr5 Economizing on materials costs. -Forge the flange by drop-forging, shank - cross-rolled part -Conservation of turning capacity

2. Strength properties of friction welded joints

Heretofore, studies of the strength of friction welded joints carried out internationally have been of the unanimous opinion

that very good static and dynamic strength results are obtained from welding with optimum friction welding parameters. The strength properties of a friction welded joint can be assessed as better than all other fused and flame butt-welded joints. The tensile strength of the welded joint exceeds the tensile strength of the basic materials because of the compression brought about in the joint region by the compression process.

Friction welded joints of sufficiently ductile materials can be bent at an angle of 180° without cracking the joint. The formation of a special grain in the bonding zone in some cases, especially in previously heat-treated components, leads to a decrease of the notch impact strength.

Specific studies confirm these statements. Figure 1 shows the tendencies of σ_B and a_b for bar-to-bar friction welded joints as a function of t_e, for diameters of 24 mm, using St 38, wherein the heating pressure Ph and the welding pressure Pw have the best values. The curves shown in Figure 1 lean towards longer heating times with increasing carbon and alloy contents.

Very little is said in the literature about the endurance properties of friction welded joints. Publications deal mainly with definite materials and shapes of construction elements. The result is comparisons of the endurance strengths of friction welded joints with the base materials and with parts that previously had been manufactured by other manufacturing processes /1/ /2/ /5/ /7/ /9/.

The endurance strength values of the basic materials were reached and exceeded uniformly, particularly in the case of construction steels and low-alloy steels. In Figure 2 are shown the results of studies carried out at the TH Karl-Marx City for the comparison of the endurance strengths of worked and unworked samples, in tensile expansion tests.

In both studied materials, the samples with bead left on reached an average strength 10 kp/mm^2 lower than the samples with bead removed after 2 x 10^6 load changes. This lower strength of the unworked samples in the area of time and endurance strength is attributable to the cracking effect proceeding from the bead as a result of the plastic deformation during the friction welding process. For this reason, the bead is removed from friction welded joints with dynamic requirements.

In operating tests of friction welded parts, for example in automobile manufacture, compressor manufacture, and railway car construction, it has been found that joints show excellent operational and strength properties under normal and extreme temperature conditions, under changing and percussive loads. Failures of friction welded joints have not yet been reported.

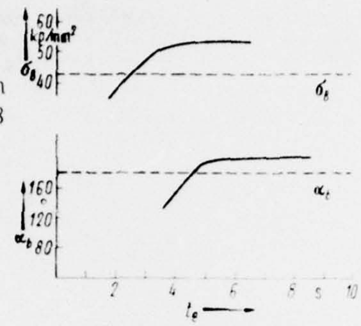
3. Closing comments

Definite criteria of configuration are to be observed by engineers and technicians for the use of friction welding in the manufacture of structures suitable for friction welding, with the required strength properties and the exigencies of economical accomplishment. The authors have assembled for this purpose a large number of recommendations for the user resulting from the studies for industry carried out in the past, and from basic investigations.

Symbols

a	mm	sheet thickness
B	mm	plate width
D	mm	diameter (discs)
d	mm	diameter (shafts)
P_e	kp/mm^2	heating pressure
P_{schw}	kp/mm^2	welding pressure
R	–	friction welding location
s	mm	plate or wall thickness
t_e	s	heating time
α_b	°	bending angle
σ_B	kp/mm^2	tensile strength
κ	–	tension ratio

Figure 1
σ_B and $\alpha_b = f(t_{et})$
bar-bar joint
diameter 24 mm
material St 38



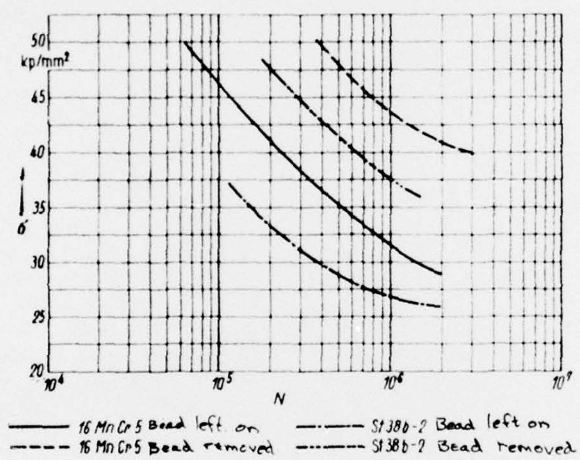


Figure 2: Terminal values for Wöhler curves (tensile-expansion-strength) of friction welded joints with bead left on and removed.

Weld diameter 30 mm, $\kappa = 0.25$

Material	St 38 b-2	16 MnCr5
Welding Data		
Ph in kp/mm^2	4	3
p_w in kp/mm^2	6	6
t_e in sec	8	10

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1. REPORT NUMBER FTD-ID(RS)I-1724-76	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FRICTION WELDED CONFIGURATIONS FOR CONSTRUCTION		5. TYPE OF REPORT & PERIOD COVERED Translation
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) S. Buchholz		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Foreign Technology Division Air Force Systems Command U. S. Air Force		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE November 1974
		13. NUMBER OF PAGES 12
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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